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WIND TUNNELS WITH ADAPTED WALLS FOR REDUCING WALL INTERFERENCE

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16. Abstract The basic principle of adaptable wind tunnel walls is explained. First results of an investigation carried out at the Aero-Space Institute of Berlin Technical University are presented for two dimensional flexible walls and a NACA 0012 airfoil. With five examples ex- hibiting very different flow conditions it is demon- strated that it is possible to reduce wall interference and to avoid blockage at transonic speeds by wall adaptation.			
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Wind Tunnels with Adapted Walls for Reducing Wall Interference

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Summary

The basic principle of adaptable wind tunnel walls is explained. First results of an investigation carried out at the Aero-Space Institute of Berlin Technical University are presented for two dimensional flexible walls and a NACA 0012 airfoil. With five examples exhibiting very different flow conditions it is demonstrated that it is possible to reduce wall interference and to avoid blockage at transonic speeds by wall adaption.

1. Introduction

The finite dimensions of a wind tunnel generally create disturbances around the model being measured. The measured results are affected by this interference and must therefore be corrected for flow field of unlimited boundaries.

If only a subsonic flow is being employed, theoretical correction methods based on the principle of wall reflection may be applied. The results achieved from pressure distribution affected by disturbances, for example, closely approximate undisturbed values. These methods do not, however, take into consideration wall influence in building different boundary layers. This becomes especially important when flow separation occurs on the model and minor changes in pressure distribution lead to major changes in flow field.

In the case of transonic flows additional effects occur. If sound velocity and the maximum flow density is attained in the narrowest flow cross-section between the solid wall and

the widest section of the model, blockage occurs. It is not possible to increase the upstream velocity for the model. This problem was met by partially opening the walls in the form of slits or perforations. Gathering exact data about wall interference by these means is, however, problematic, since it is difficult to evaluate the influence on flow around the model of flows passing through the wall which are greatly affected by turbulence as well as secondary flow effects near the wall [9]. This again especially affects model flows with boundary layer transitions.

With flexible wind tunnel wall adaptation a procedure has been created for substantially reducing wall interference and avoiding blockage at transonic speeds.

2. The Principle of Wall Adaptation

The principle of flexible wind tunnel wall adaptation is based on the adjustment of wind tunnel wall to the flow form of a flow unlimited in all directions. This conception is illustrated in Fig. 1.

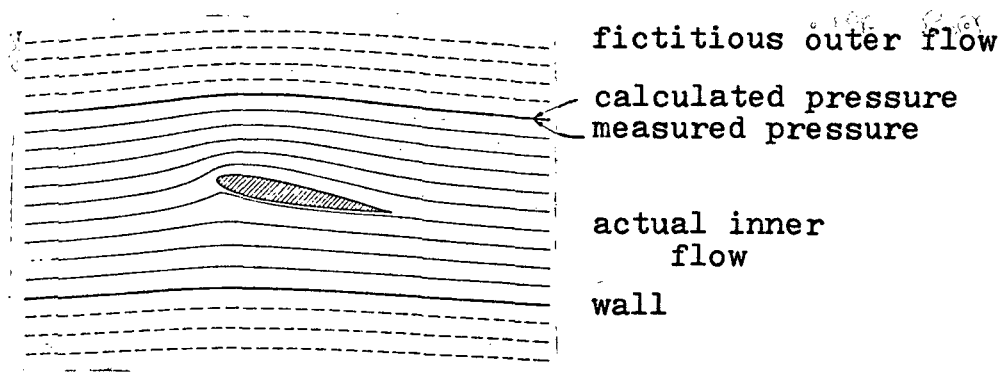


Fig. 1: Principle of Wall Adaptation

This is a sketch of the flow field in a wind tunnel expanded to include a theoretical fictitious outer field as a

continuation of the image of the actual inner flow on the other side of the wall. The essential consideration for wall adjustment is that a flow surface cannot take up any force, i.e. the pressure on both sides of the flow surface must be equal. Pressure distribution along the inner side of a wall can be measured by means of a series of static pressure holes. Pressure distribution along the outer side of the wall can be calculated for the fictitious outer flow since wall contour is known. When the inner measured pressure distribution equals the outer calculated pressure distribution, then the wall contour is correct and corresponds to the desired flow form.

Since the inner pressure distribution normally differs from the outer pressure distribution, the form of the wall must be corrected. For this the difference between the two pressure values

$$\Delta c_p = c_{p \text{ innen}} - c_{p \text{ außen}}$$

a. b.

Key for both equations on
this page: a. inner
 b. outer

is employed to obtain a pressure distribution for the fictitious outer flow with the control factor $0 < K < 1$.

$$c_{p \text{ außen}}(n) + K \Delta c_p \rightarrow c_{p \text{ außen}}(n+1)$$

a. b.

This pressure distribution is used to calculate the appropriate wall contour for each control step. The new wall form is readjusted until the difference between the two pressure distributions remains within a defined tolerance value.

The substantial advantage of this procedure is that both measurement and calculation apply solely to the wall with a relatively small degree of curvature both simple to measure and to calculate. Neither the form of the measured model nor the flow processes on the airfoil surface such as boundary layer trans-

itions and separation is a factor in the calculations and does not normally have to be known.

The simple description of the principle of wall adaptation should not obscure the fact that there are a number of problems to be expected in the practical application. The influence of boundary layer at the wind tunnel walls is, for example, especially important when strong pressure gradient or even compression impulses define the flow field. The first basic investigations by M.J. Goodyer[1] and J.-P. Chevallier[2] on the procedure of wall adaptation have resulted in problems above all in the case of high angle of pitch and transonic flows. Here the control procedure was extremely time consuming in some cases. Goodyers investigations have been limited to incompressible flows ($M = 0.1$) up to now. High angles of pitch ($\alpha > 8^\circ$) delivered unsatisfactory results. Long regulating time of 240 minutes is probably due in part to a large number of positioning elements (15 + 15). Chevallier's investigations were carried out with a 5% geometrical barrier in the case of transonic flows ($M = 0.80$ to 0.87). A flow free of interference was assumed from the convergence of the wall correction. Detailed pressure distribution measurements for the airfoil have not been published, so that only a limited evaluation of results is possible.

3. First Results of Investigations at the Technical University TU Berlin

3.1 Test Equipment

The high velocity tunnel of the Aero-Space Institute of the TU Berlin, driven by a hot water jet ejector, was employed for the experimental investigation. Air is taken in the surrounding atmosphere. A new convergent nozzle and a wind tunnel with adjustable flexible walls was constructed for the tests (Fig. 2).

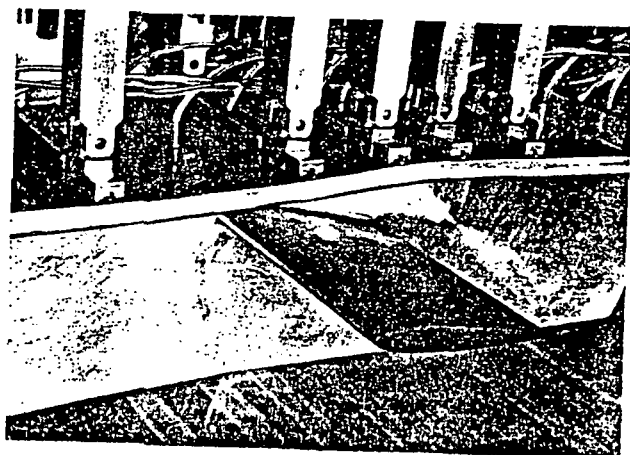


Fig. 2a: Wind Tunnel Provided with Flexible Wall Adaptation

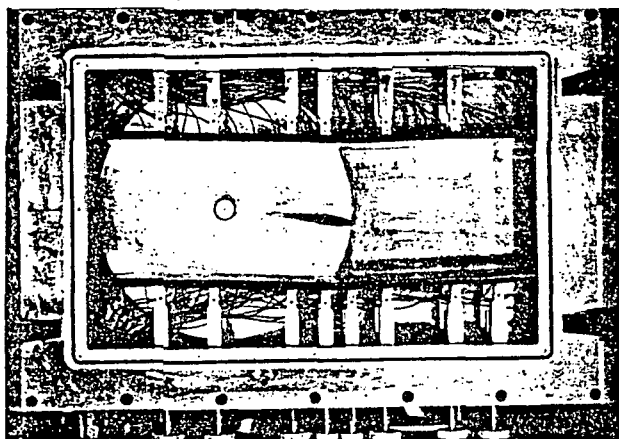


Fig. 2b: Positioning Elements of Wind Tunnel

Wind tunnel cross-section is $15 \times 15 \text{ cm}^2$ and length is 69 cm. The flexible walls are 1.2 mm thick and were made of fiberglass reinforced synthetic material. The shape of lower wall may be altered by means of six double pin jointed adjustable members, the shape of upper wall by means of eight such members.

The NACA 0012 airfoil with an airfoil depth of 10 cm, already subjected to extensive airfoil measurements, was chosen as model. This airfoil results in a geometric barrier of 8 %. In the middle section of airfoil ten 0.5 mm diameter pressure holes each were positioned on the upper and lower sides. Further 4×4 control pressure holes were placed at a distance of 30 mm to the left and right

of the middle section in order to evaluate the limits of even flow circulation.

3.2 Theoretical Simulation

A computer program was set up for a theoretical simulation of adjustment of wall adaptation to define a friction free flow field around an airfoil in a wind tunnel with randomly formed

walls. The program is based on the panel method [10] and supplies the pressure distribution along the inside of the wall.

A second program, employed in the same manner for experimental adjustment, makes calculation of wall contour by a given pressure distribution possible. Thus the form of wall corresponding to pressure distribution in the fictitious outer flow is calculated.

Figure 3 demonstrates examples of wall forms calculated for individual control steps when flow around NACA 0012 airfoil is

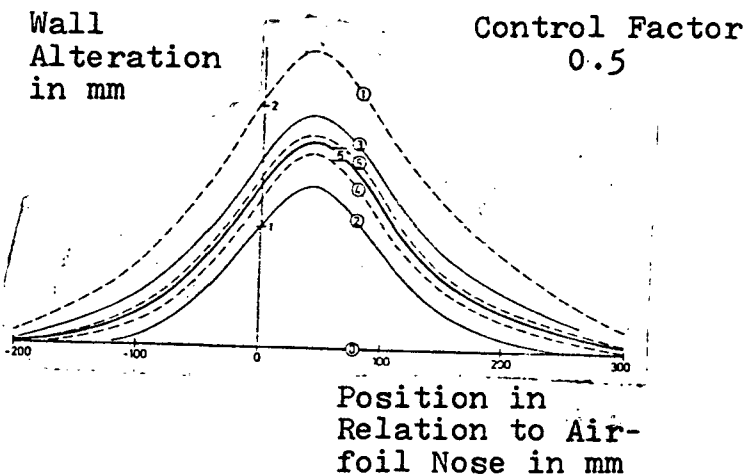
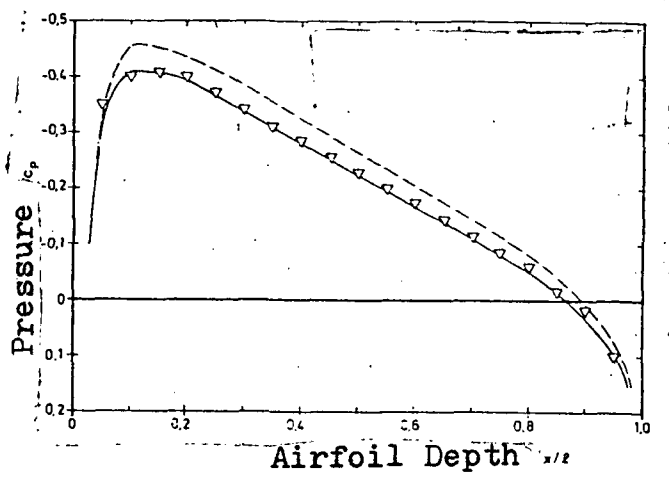


Fig. 3: Wall Alteration for Airfoil NACA 0012 at $\alpha = 0^\circ$, $M = 0$ and 8 % Geometric Barrier. Calculated Simulation of Control

symmetrical. Starting shape is the even wall (iteration step 0). In this case maximum wall alteration is of the order of 2 mm.

The calculated results serve as basis for wind tunnel design to determine suitable positions for positioning elements and to indicate range of maximum expected alteration.

A further calculation result is shown in Fig. 4. For incompressible flow it shows pressure distribution for NACA 0012 airfoil when wall is even with 8 % geometric barrier and when wall is adjusted (6th control step). This is an illustration of the scale of wall interference. Interference-free comparison values of an experimental investigation[3] were plotted to check the calculation method of this test.

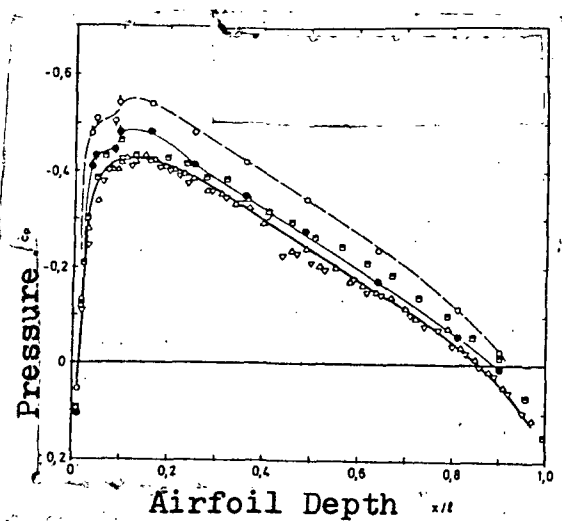


---Even Wall Theoretical Values
 —Adjusted Wall TU Berlin
 ▽ Measurements Free of Interference NASA

Fig. 4: Pressure Distribution for
 NACA 0012 Airfoil at $\alpha = 0^\circ$,
 $M = 0$ and 8 % Geometric
 Barrier.
 Theoretical and Experimental
 Results

3.3. Experimental Results

The experimental results described in the following are
 based on five selected flow conditions.



-o- Even Wall TU Berlin,
 $Re = 0.50 \times 10^6$
 • Adjusted Wall
 Δ Free of Interference ONERA,
 $Re = 1.85 \times 10^6$
 ■ Free of Interference NASA,
 $Re = 3 \times 10^6$
 — Airfoil Catalogue Abbott & Doenhoff

Fig. 5: Pressure Distribution for
 NACA Airfoil 0012 at $\alpha = 0^\circ$,
 $M = 0.222$

In the first example (Fig. 5) the incompressible flow circulates around the airfoil symmetrically. When the control factor is $K = 0.25$ the wall adaptation is already achieved after the second control step. Calculation time for a control step amounted to 30 seconds on a TTR 440. Comparison values are taken from [6,7,8]. All values were converted via the Prandtl-Glauert factor to Mach number $M = 0.222$. The differences in pressure distributions may possibly be explained in part by the different Reynolds numbers. It still remains to be determined what influence model inaccuracies and the relatively large pressure holes had on the measurement results of this test. It may, however, already be stated that the wall interference was reduced to a great extent by adjustment of wind tunnel wall shape.

The second example (Fig. 6) concerns the pitched airfoil, also with incompressible flow circulation. The experimental values from [7] can only be considered rough approximations for comparison purposes, since the pressure balance at wing edge influences pressure distributions for a wing with relatively small extension (right-angle wing with $\Delta = 3$) at pitch.

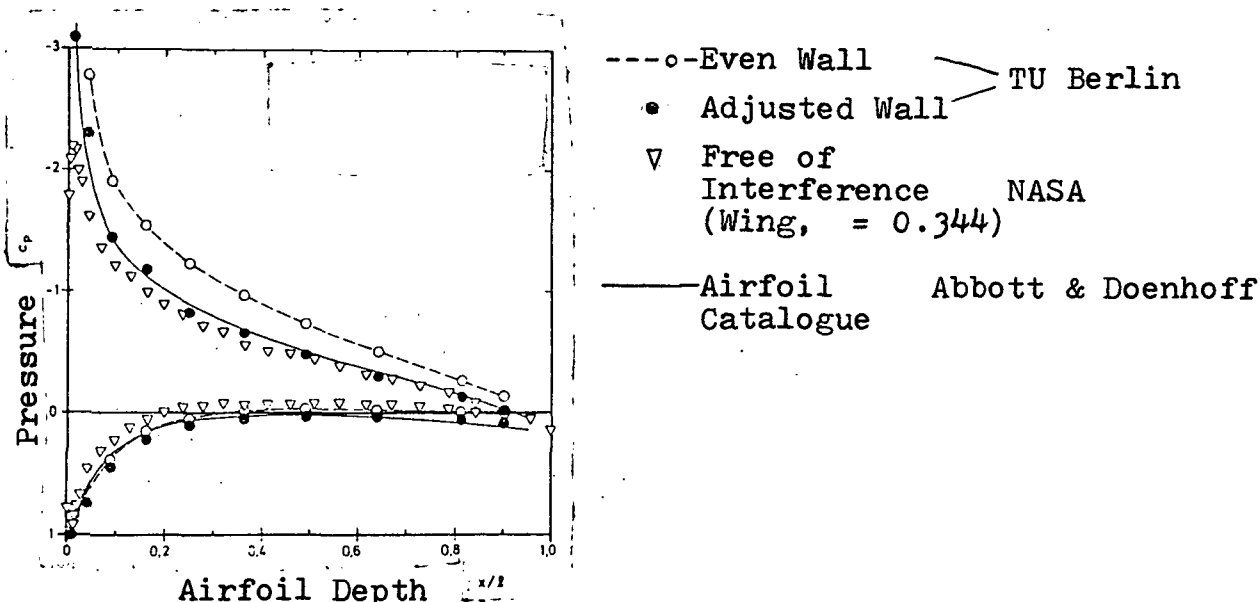


Fig. 6: Pressure Distribution for
NACA 0012 Airfoil at $\alpha = 6.75^\circ$,
 $M = 0.224$

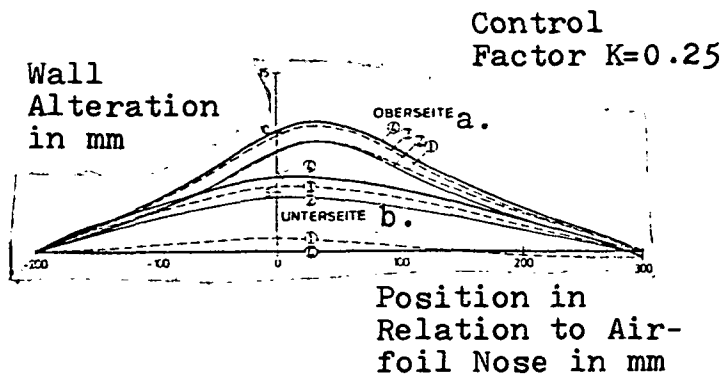


Fig. 7: Wall Alteration for NACA 0012 Airfoil at $\alpha = 6.75^\circ$, $M = 0.224$ and 8% Geometric Barrier. Experimental Results at Various Control Steps
Key: a. upper side
b. lower side

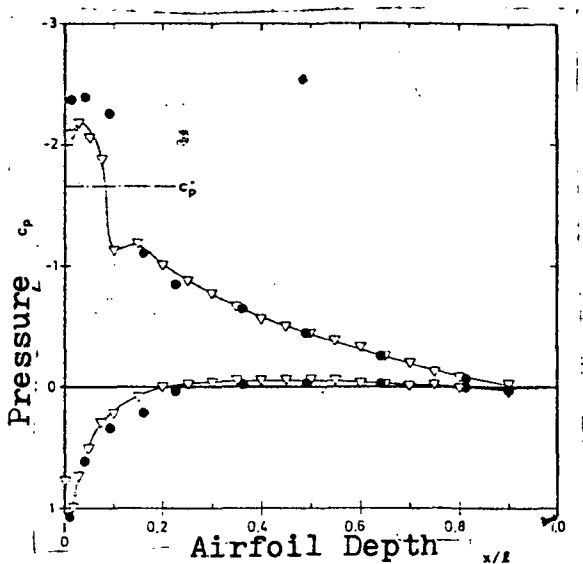


Fig. 8: Pressure Distribution for NACA 0012 Airfoil at $\alpha = 6^\circ$, $M = 0.55$

- Adjusted Wall, TU Berlin, 4th Iteration, 8% Geometric Barrier, $Re = 1.1 \times 10^6$
- ▽ Free of Interference, Calspan, 0.75% Geometric Barrier, $Re = 1.0 \times 10^6$

As expected the upper and lower wall exhibit different behavior (Fig. 7) when airfoil is pitched. In the first control step the lower wall remains almost even while the upper wall undergoes strong alteration.

The third example (Fig. 8) is valid for a slightly supercritical flow below the blockage Mach number $M = 0.710$. The comparison measured values from [4] were obtained with an airfoil of 0.5 ft. depth in an 8 ft. Calspan wind tunnel.

In the case of the fourth example (Fig. 9) the flow Mach number already causes blockage when walls are even. In the first iteration step a wall form was set calculated as the wall adaptation for $M = 0.222$. Since a flow blockage occurs even after the second iteration step, the consequent rapid

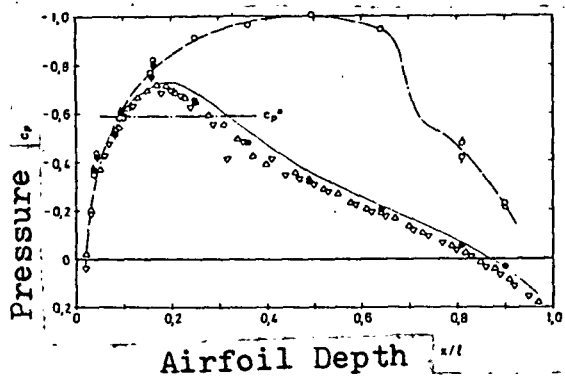


Fig. 9: Pressure Distribution for NACA 0012 Airfoil at $\alpha = 0^\circ$, $M = 0.76$

- o- Adaptation (2nd Iter.)
- Adjusted Wall (5th Iteration)
- $\nabla \Delta$ Free of Interference
- Free of Interference

TU Berlin	$Re = 1.38 \times 10^6$ $M = 0.759$
ONERA	$Re = 4.01 \times 10^6$ $M = 0.756$
NASA	$Re = 1.7 \times 10^6$ $M = 0.75$

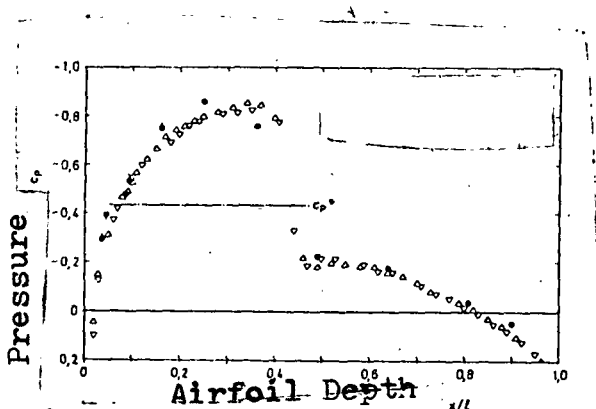


Fig. 10: Pressure Distribution for NACA 0012 Airfoil at $\alpha = 0^\circ$, $M = 0.80$

- Adjusted Wall, TU Berlin
 $Re = 1.41 \times 10^6$, $M = 0.797$
- $\nabla \Delta$ Free of Interference, ONERA
 $Re = 4.09 \times 10^6$, $M = 0.803$

adjustment of walls is remarkable. Comparison values here were taken from [6] and [3].

Finally the fifth example (Fig. 10) shows a relatively strong supercritical flow with extensive supersonic zone and strong compression impulse. Starting wall form was the adaptation calculated for $M = 0.759$ and led once again to initial flow blockage. The wall adaptation was achieved after three iteration steps. Comparison values come from [6]. The differences in pressure distributions in impulse area are typical

for the differences in Reynold numbers present here.

4. Summary and Future Work

The first results demonstrate that wall interference is reduced by wall adaptation and that a blockage of flow can be avoided in the case of supercritical flow. The work spent on positioning members and the time consumed for calculations remain within reasonable limits. This is especially the case considering an 8% geometric barrier corresponding to approximately three times the usual order of magnitude allowed in airfoil studies.

The main emphasis for continuation of research work at the TU Berlin is centered on the following points:

- In an expansion of test spectrum the NACA 0012 airfoil is to be investigated in the range of stalls as well as with very high Mach numbers. In addition a supercritical airfoil is to be measured under similar conditions.
- The test results for airfoil are to be analyzed in detail and supplemented by flow field measurements to find the cause of measurement inaccuracy and residual interference.
- The control procedure is to be automated and improved by employing a process computer.
- The wall adaptation procedure is to be further developed in regard to application in three-dimensional flow studies. For this application initially the wind tunnel with two flexible walls and then a new wind tunnel with eight flexible walls is to be investigated.

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